NASA GODDARD SPACE FLIGHT CENTER

Using NASA's Invasive Species Forecasting System to support National Park Service decisions on fire management activities and invasive plant species control.

Response to NASA **Cooperative Agreement Notice: NN-H-04-Z-YO-010-C**

A Partnership between NPS and NASA Goddard Space Flight Center proposing an "Integrated System Solutions (of Earth science for applications of national priority)"

NPS PI:
Nate Benson
National Interagency Fire Center National Park Service
National Park Service
Boise, Idaho 83705-5354

NASA PI:
Jeff Morisette
Science lead: NASA Goddard Space Flight Center Invasive Species Forecasting System
NASA Goddard Space Flight Center
Greenbelt Maryland, 20771

CSU PI:
Brad Welch
Invasive Species Monitoring Coordinator
National Park Service, Inventory and Monitoring Program
Fort Collins, CO 80525

National priority applications related to the proposed work

Carbon Management
Disaster Management
Ecological Forecasting
Invasive Species

Science for Society
Accelerating the realization of economic and societal benefits from Earth science, information, and technology
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Abstract

Two major sources of ecological disturbance are fire and invasive species. They are not independent. Both are major issues affecting land management decisions through the National Park System. The proposed work will allow the National Park Service to enhance land management decisions related to invasive species and fire management. The approach is to utilize existing Earth Science resources to better understand the interaction between fire, burnt area, and invasive species, and then to utilize this understanding to better manage National Park lands in such as way as to respect the natural ecological significance of fire while guarding against alien plant invasion. The Earth Science tools to be used are satellite-based active fire and burn scar mapping available through NASA Earth Observing System (EOS) resources and invasive species habitat modeling available through the existing, joint NASA/USGS "Invasive Species Forecasting System" (ISFS).

The methodology is developed by focusing on three park "systems:"

1) National Parks throughout Alaska,
2) The greater Yellowstone/Tetons area, and
3) The Sequoia & King area.

For each of the three focus park systems, we will:

- Model one or more invasive species' habitat through the region.
- Create maps of likely invasive species habitats throughout the region (through the ISFS).
- Establish a record of active fire and burnt areas since 2001, overlay this record with the invasive species habitat maps, and explore the relationship between invasion and disturbance from fire.
- Using that relationship, use up-to-date burnt area locations and invasive species habitat maps to inform park managers of critical areas that may need treatment against invasion.
- Use invasive species habitat maps to identify areas within prescribed burn units that have a likely potential of invasion.
- Extrapolate in space and time post-burn ecological assessment conducted at limited field locations by modeling the relationship between the ecological assessment point values and remote sensing and GIS layers (through the ISFS).

Steps A and B will be iterated as new field data are collected and improved remote sensing and GIS layers become available. This iteration highlights the use of the high temporal resolution of some remote sensing imagery (e.g., MODIS) and the efficient and powerful computation capacity of the ISFS. The parallel computing environment and data infrastructure available through the ISFS will allow this iteration to be efficient and low cost.

While the proposed work will focus on three park systems, the objective is to develop a mechanism to integrate the ISFS into both national planning and plans of individual parks. The ISFS is currently being transitioned to an operational capacity at USGS National Institute for Invasive Species Science. The efforts proposed here will ensure that the NPS invasive species and fire ecology programs can maximize the use of that operational system.

Project Plan and Approach

2.1. Overview: Focal management issues of this proposal

Invasive species are organisms, usually transported by humans, that establish themselves in and then overcome otherwise intact, pre-existing native ecosystems. Invasion of non-native species, together with habitat destruction, has been a major cause of extinction of native species throughout the world. There is an increasing realization of the ecological costs of biological invasion in terms of irretrievable loss of native biodiversity. The US is particularly vulnerable to invasions by non-native species because of its high ecological diversity (NRC, 2000). (See *www.invasivespecies.gov* for more information.) In the past 100 years, non-indigenous plants, animals, and pathogens have been introduced at increasing rates into US ecosystems. A growing number of these species are becoming invasive, contributing to declines in native species and to changes in ecosystem function. Direct costs to the American economy alone are estimated at $100-200 billion per year, greater than all other US natural disasters combined (NISC, 2001).

Fire and invasive plant species are two major sources of ecological disturbance affecting land management decisions made by the National Park Service (NPS) and its partners. Each of these disturbances has the potential to exacerbate the other. Consequently, there is a need to address the management of fire and invasive species in concert.

Each national park constructs management plans and makes decision on (1) the monitoring and control of invasive species and (2) fire ecology programs that address wildland fire suppression activities and the use of prescribed burns to maintain biodiversity.

Existing research shows an interaction between fire management activities and invasive species (Freckleton, 2004; Keeley, 2003; Whitlock, 2001). Fires disturb the landscape and can change soil characteristics and the canopy structure. Successful plant invasions can alter the fire regime (vegetation and fuel structure), perpetuating the existence of the invasive species with continued effects on the fire regime. Additionally, the timing of prescribed burns may influence the likelihood of invasion (Caprio, 2004). It has been suggested that researchers focus both on the mechanisms by which invasive plant-fire regime cycles become established and on the management tools that can be used to reverse these changes or otherwise mitigate their negative effects. (Brooks et al., 2004).

The large area extent of NPS and adjacent lands make remote sensing imagery a valuable information asset for the management of these large areas. Advances in remote sensing vegetation and fire products and ecological modeling provide exciting new opportunities to better understand the relationship between fire and plant invasion and use that understanding to control against plant invasion. This project will provide the NPS with tools to help manage lands in a way that respects the natural ecological significance of fire while guarding against alien plant invasion. This objective will be accomplished by combining satellite-based fire active and burn scar mapping available through NASA Earth Observing System (EOS) resources and invasive species habitat modeling available through the joint NASA/USGS “Invasive Species Forecasting System” (ISFS). A recent “Memo of Understanding” (MOU), calls for increased collaboration between NASA and NPS (see letter of support from Lynne Murdock). This project will build such a collaboration to address specific and critical management needs within the NPS.

We will pilot our approach in the Alaska, Sequoia and Kings Canyon, and Yellowstone/Grand Tetons National Parks. In each park system, fire is a dominant, natural ecosystem process addressed through fire management programs. Each park has invasive species management strategies that emphasize prevention and early detection, with partnerships and management plans that involve the surrounding land owners. The fire and invasive species management experience at these parks will provide a reliable foundation on which the proposed decision support tools may be built. Further, the existing fire and invasive species programs at these parks are supported by data sets that include species inventory, research results, monitoring plots, and remote sensing and GIS data. These data sets will be utilized and complemented in this proposal. The park systems differ in their ecological and land use contexts and encompass a range of ecosystem types that vary with respect to fire potential and invasive species potential. This variation offers potential for broader application of the final products to other US park systems

Due to the interaction between fires and invasive species, we propose to use the joint USGS/NASA Invasive Species Forecasting System (ISFS) to provide information on:

1) How best to monitor and reduce the likelihood of plant invasions within and around national parks, in light of both planned (prescribed) and unplanned (wildland) burns.

2) When and where to conduct prescribed burns so that the risk of plant invasion is minimized.

This project plan describes:

- The fire ecology and invasive species management and policy issues within the NPS.
- Our rationale for focusing on three park "systems" that provide specific fire ecology and invasive species decision support issues related to each system.
- The fire and burn scar mapping products available through existing Earth Science resources and the invasive species habitat modeling available through the ISFS.
- Our approach to applying these resources to better inform land management decisions within the three focus park systems.
- Team and partnership arrangements, plans to transition to an operational system that can be applied to National Parks, issues affecting project success, and expected results.

An overview of the project plan components is depicted in Figure 1.

Each component shown in this figure is discussed below.

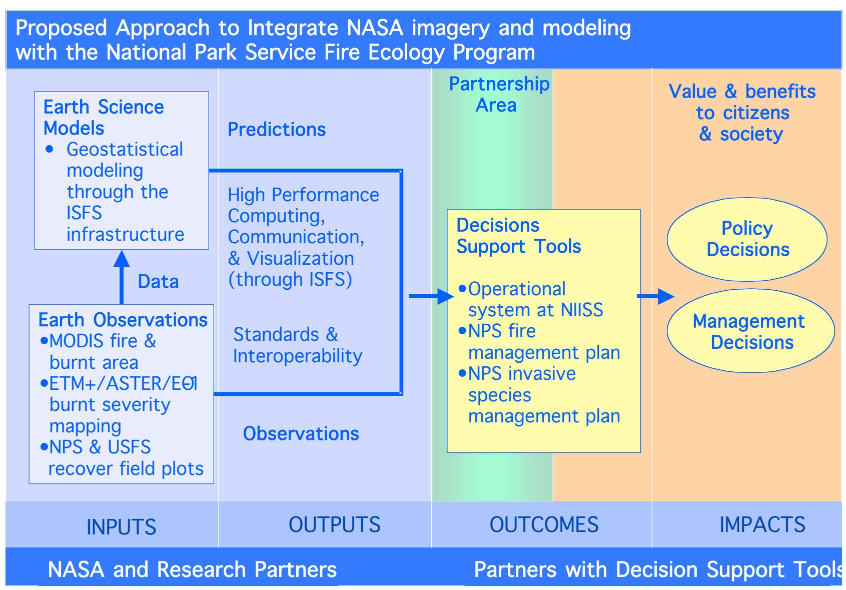
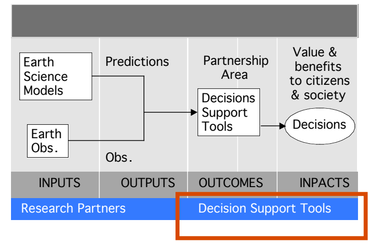


Figure 1. Invasive species and fire ecology programs at the three focus park systems.



Individual parks manage and monitor invasive plants at the local scale. Rapidly deployed Exotic Plant Management Teams assist parks with high-priority invasions while the Inventory and Monitoring Program works across networks of parks to survey and monitor invasive plant incursions. The Fire Program monitors plant invasions as a component of their standard fire monitoring protocols. Collectively, these programs operate and report to databases that function at the local, regional, and national level to support decision-making for natural resource managers. In all cases, prevention, prediction, early detection, and prioritized control of plant invasions are the management priorities, requiring tools such as those proposed here to make scientifically sound management decisions. Specific fire and invasive species issues related to each participating park system are summarized below.

Fire and invasive species issues in Alaska

Alaska has not yet experienced the severity of invasive species problems seen elsewhere in the US. Its climate and isolation have protected native ecosystems, but human population, development, and transportation are increasing. Invasive species in Alaska have generally colonized areas of human disturbance, especially along roads and trails and at recent construction sites. Several species, however, have shown the ability to invade naturally disturbed sites, including river floodplains and wetlands, such that they pose a threat to vast land areas of similar character throughout Alaska. Meanwhile, notoriously problematic species from other states arrive in small populations that may threaten native ecosystems in the future. Population centers have seen the greatest influx and diversity of invasive plants, while Alaska's National Parks are remote and less impacted. This situation is tenuous, however, for the parks are also experiencing the arrival of new species and expansion of their ranges both inside and outside park boundaries. Consequently, the importance of early detection and rapid response cannot be overemphasized for any region of the state. Surveys have been completed for invasive plants in almost all Alaskan National Parks, providing information for ongoing early detection and for prioritization, control, and monitoring of established populations. Statewide coordination is essential for sharing information and resources to prevent, detect, control, and monitor such infestations.

Very little is known about the interactions between fire and plant invasion in Alaska. Because invasive plants have been limited in distribution to human disturbances while fires have burned in wildlands, there has been little to no spatial overlap. During the summer of 2004, however, this situation changed. Enormous acreages burned in Interior Alaska that were adjacent to or overlapped human disturbance corridors known to harbor invasive plant infestations. Furthermore, for the first time in recent history, firefighters from other states were deployed to suppress Alaskan fires in 2004, potentially introducing invasive plant seeds or material into remote areas on clothing, gear, and vehicles. Subsequent regrowth in 2005 will bring morel mushroom harvesters to these areas and another potential pathway for plant invasion. As a natural disturbance, fires may provide suitable habitats for invasive plant colonization in ecosystems previously resistant to invasion. The invasive plants in Alaska are mostly pioneer species that thrive on newly disturbed ground where other plants are not yet established. Along with river floodplains, wildfires provide the greatest potential vector for large-scale dispersal of invasive plants into native ecosystems in Alaska. For example, the 2004 Woodchopper Fire complex burnt part of the Coal Creek drainage in Yukon-Charley Rivers National Preserve (YUCH), an area known to harbor invasive plants. Bird vetch (*Vicia cracca*), one of the species of greatest concern in the entire state, was recorded in the same area for the first time in the preserve. The NPS will monitor the YUCH area closely in 2005, as will other Alaskan agencies over larger burnt areas, and these efforts may yield more information on how invasive plants are related to fire in Alaska. Unfortunately, by the time we investigate the relationship, the invasion will be underway. Forecasting these interactions in Alaska would be extremely valuable for making decisions about invasive plant management with regard to wildfire.

Fire and invasive species issues for the Sequoia & Kings Canyon region

Baseline surveys of non-native plants were conducted in Sequoia and Kings Canyon National Parks (NPs) from 1996 to 1998. Over 194 non-native plant taxa were found. Of these, 74 are considered a threat to native ecosystems, and 50 are in the highest priority management category (Gerlach et al., 2003). Sequoia and Kings Canyon NPs began a comprehensive invasive plant management program in 2001, and the staff actively manages about 20 species. Non-native species richness and abundance is strongly negatively correlated with elevation (Gerlach et al., 2003), which ranges from 400m in the foothills to 4417m on the summit of Mt. Whitney. Herbaceous biomass in foothill grasslands is 99% non-native species (Parsons and Stohlgren, 1989) with up to 71 species found in developed areas, while elevations above 2,400m are usually free of non-native plants (Gerlach et al., 2003). Because of this elevation gradient, most of Sequoia and Kings Canyon's wilderness areas are now largely unaffected by non-native plants. To maintain this condition, in 2004 the superintendent issued a management directive for preventing the introduction and spread of invasive plants, with strategies addressing stock use, fire, and wilderness operations. However, a few species already broadly distributed at mid-elevations (1300 to 2300m) are a threat to native ecosystems, and appear to be correlated with fire. These species include *Bromus tectorum* (cheatgrass), *Cirsium vulgare* (bull thistle), and *Verbascum thapsus* (wooly mullein). Early detection and control of these species both before and after fire is a high-priority management objective, and two projects in 2004 were targeted to this objective. Other species of concern include *Arundo donax* (giant reed), *Rubus discolor* (Himalayan blackberry), *Phalaris arundinacea* (reed canary grass), *Carduus pycnocephalus* (Italian thistle), and *Centaurea solstitialis* (yellow star thistle), which is approaching park boundaries but not yet present in the park.

Sequoia and Kings Canyon NPs have played an active and often leading role in developing and implementing fire management activities within the NPS. It was recognized early that the lack of fire as a process in many park ecosystems was leading to dramatic and often undesirable changes to natural landscapes. Since the late 1960s the parks have had a very active burn program, including prescribed fire and wildland use fire, to restore or maintain fire in many park ecosystems. During the 1990s considerable burning was carried out in lower elevation pine-dominated conifer forests in Kings Canyon. By 1998 a striking increase in *Bromus tectorum* was noticed and appeared to be associated with disturbance related to fire and stock usage. A moratorium on burning in the canyon was initiated by park fire managers until more could be learned about the role of fire and this exotic. Of concern to park fire and resource managers is whether undesirable shifts in plant communities are occurring and whether there are any mitigation actions that could be taken prior to occurrence. Fire's specific role in the spread or establishment of invasives is still poorly understood but such information will become increasingly important in managing the parks. Potentially understanding where susceptible sites for invasive species establishment exist and how these relate to disturbance by fire will be important in implementing management actions not only following fire occurrence but in designing pre-fire strategies that can limit future impacts.

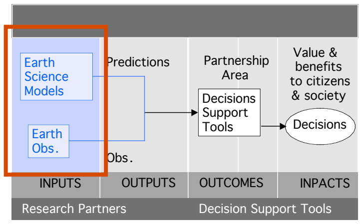
Fire and invasive species issues for the Yellowstone/Grand Tetons regions

Yellowstone National Park's exotic plant management plan was completed in 1986 and has changed little since the mid-1980s with the exception of increased emphasis on cooperative partnerships and prevention. The park has been documenting annual control efforts since 1993. To date, 201 non-native plant species have been found in the park. Due to staff and budget limitation, about 20 species are targeted for eradication or containment. Less invasive or more broadly dispersed species are less actively treated. Over 95% of the high-priority species are found along the park's roads and in developed areas. However, Canada thistle and Dalmatian toadflax are broadly dispersed in the park's backcountry and are a management concern. With the exception of mapping backcountry populations of Dalmatian toadflax in the park's North District, relatively little management is occurring on these two species. However, they were recently addressed in a multi-species backcountry survey for invasive plants in the northern portion of the park by staff from Montana State University (MSU) funded by the NPS Greater Yellowstone Inventory and Monitoring Network. Data included habitat types and disturbances where invasive plants were encountered.

Relating fire to invasive plant management is a growing topic of concern for resource managers. Invasive plants take advantage of recently burned areas, especially when there is a population of invasive plants near the newly burned area. Following the 1988 fires in Yellowstone, invasive plants had the opportunity to spread into many burned areas. Park staff knew the locations of most high-priority species that existed near burned areas and focused treatment efforts to contain these populations and prevent their spread. During the past thirty years, 34 vegetation-monitoring plots have been located throughout the park to monitor the role of fire on the landscape including its effect on plant invasion. About 50% of the plots have some non-native species present, generally low management priority species. But Canada thistle is well represented.

From a strategic viewpoint regarding invasive plants, it would be helpful to determine the approximate number of acres and locations currently infested by Canada thistle and Dalmatian toadflax. This information could be used to help evaluate and prioritize areas for prescribed fires and identify possible burned area rehabilitation needs to mitigate invasive plant spread following fires. Information could be used to assess possible future use of biological controls, establish baseline information on areas susceptible to invasion, and monitor the spread of these species. If budgets and program priorities permitted, we could identify high-value vegetation communities to monitor and attempt to protect these areas from invading species. On the Greater Yellowstone Area (GYA) scale, evaluating and monitoring the spread of leafy spurge southwest of the park on the Caribou-Targhee National Forest would be beneficial in helping the park and US Forest Service establish both fire and invasive plant treatment priorities and schedules. Currently a cooperative database consisting of over 114,000 invasive species locations in the GYA for 65 species could be used to evaluate the proposed support tool. This could involve park staff cooperating more actively with the Forest Service on treatments outside the park to help slow or stop the spread of leafy spurge and protect park resources. Better knowledge of the areas susceptible to invasion by high-priority invasive plants, especially on the expanding edges of the populations and in areas of fire disturbance, would be helpful to management.

2.2. Earth science results to be employed



Three "Earth Science results" will support our proposed effort:
1) the NPS burn severity maps,
2) MODIS land products, and
3) the USGS/NASA Invasive Species Forecasting System.

NPS Burn Severity Mapping

A major component of fire ecology within the NPS is the joint NPS-USGS National Burn Severity Mapping Project, which quantifies fire effects over large, often-remote regions and long time intervals. It reflects collaborative efforts to bring previous research into operational implementation for fire managers and scientists. The project focuses on NPS Units and adjoining lands throughout the US, mostly beginning with fire-year 2000. The goal is long-term monitoring by means of standardized geographic databases employing consistent measures of "burn severity," viewed as a scaled index gauging the magnitude of ecological change caused by fire. The process uses Landsat 30-meter data and a derived radiometric value called the Normalized Burn Ratio (NBR). The difference between pre-and post-fire NBR datasets is computed to determine the extent and degree of landscape change resulting from fire. Depending on timing of post-fire acquisitions and use of similar phenology in scene pairs, the differenced NBR is hypothesized to correlate with ecological burn severity, usually defined by thresholding NBR into ordinal fire severity classes (e.g., unburned, lightly burned, and severely burned). Results are appropriate for a landscape perspective of burns, revealing their spatial heterogeneity and how fires interact with vegetation and topography at moderate to high scale and resolution (http://burnseverity.cr.usgs.gov).

Burnt severity assessments are conducted by considering the difference between pre-burn NBR and post-burn NBR. *Initial assessment* uses the image acquired directly after the fire, and *extended assessment* uses the scene from approximately one year later.

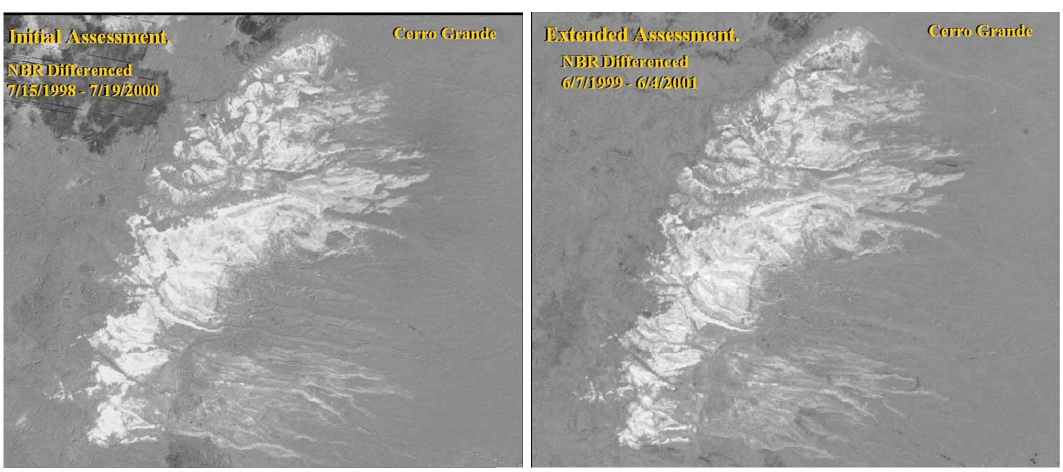


Figure 2

Figure 2 shows an example of the initial and extended assessment for the Cerro Grande, New Mexico fire site. The fire burned mostly in early May 2000. The image shows different degrees of severity and different responses between the two scenarios. The Extended Assessment captures green-up of the following year, and the severity is somewhat lower than in the initial assessment.

MODIS fire, burnt area, and vegetation index products

In addition to the NPS's National Burn Severity Mapping project, we will also use products from the MODIS sensor on board the Terra and Aqua satellites (Justice, 2002a). MODIS products provide region-wide information at a high temporal resolution (daily to 16 day) but moderate spatial resolution (250m to 1km). Our general strategy is to use the MODIS products to locate regions that warrant further investigation through the acquisition of higher spatial resolution satellite imagery and/or field observations. The MODIS 1km day and night active fire product has been generated systematically since MODIS launched (with data availability starting in early 2000, Justice et al., 2002b). The MODIS burned area product maps both the 500m location and approximate day of burning using a change detection approach applied to the MODIS near-infrared and shortwave infrared bands (Roy et al., 2002). The MODIS burned area product will be generated systematically for all MODIS data collected since November 2000 (Roy et al. 2005b) and this entire time series will be available for the proposed work. Together, the MODIS active fire and burn area products will provide "near-real-time" assessment (fire within hours at 1km resolution and burn areas within weeks at 500m resolution). For the proposed effort, the active fire and burn area products will direct the acquisition and analysis of higher spatial resolution burn severity maps. Once an area has been burnt, the 250m spatial resolution 16 day MODIS vegetation index product (Huete et al., 2002) will be used to monitor post-burn vegetation recovery. Existing work within the ISFS has shown the statistical significance of the temporal signal from the MODIS vegetation index for predicting species richness (Morisette et al., in review). The temporal signal for burnt area will be used here to detect the existence and timing of plant canopies recovering after the fire.

NASA/USGS Invasive Species Forecasting System

The USGS has developed geostatistical methods to integrate multiple types and scales of data, including satellite images, aerial photography, and ground data of various resolutions to map these resources (Stohlgren et al., 1997a-b, 1999). The ISFS provides a framework for using USGS's early detection and monitoring protocols and predictive models to process NASA and commercial satellite data and create on-demand, regional-scale assessments of invasive species patterns and vulnerable habitats. When fully implemented the forecasting system will be a dynamic and flexible mechanism for generating predictive maps of invasive species habitat (Schnase et al., 2002). These maps—when combined with economic, environmental, sociological, geographic, and other types of data and models—provide a critical component of an invasive species decision support capability that will be used by private and public national, state, and local management agencies for remediation, management, and control. The ISFS process (Figure 3) accepts as input

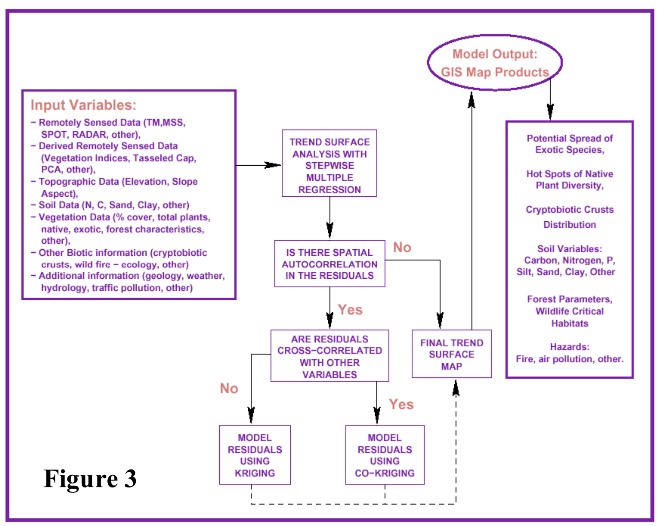


Figure 3

a collection of field-measured response variables (e.g., presence/absence of a given species) and ecological attributes to be used as predictor variables (e.g., topographic data, species data, soil characteristics, satellite-derived vegetation indices). The modeling component of ISFS calculates statistical relationships between predictor variables and response variables. The relationship is applied to produce a predicted surface. Residuals from the predicted surface are further analyzed for spatial structure using kriging and co-kriging. The results are brought together to produce a refined spatial prediction that is accompanied by an estimate of uncertainty. The process's ability to produce both predictive maps and maps of uncertainty significantly increases its value for decision support, since useful predictions are ultimately dependent upon a quantifiable understanding of error (OSTP, 2001; Smith et al., 2001). The techniques comprise a core component in the decision support activities of the USGS and partner federal and state agencies. To scale these methods to larger applications, NASA's role in the ISFS effort is to improve the computational performance of the statistical/geostatistical algorithms (Pedelty et al., 2004) and to increase the use of EOS and other remotely sensed data resources (Morisette et al., in review).

Data from the May 2000 Cerro Grande Wildfire Site was modeled using the USGS/ISFS. Figure 4 shows an example of the type of predictive map used by the USGS invasive species decision support. The largest number of invasive species is within the central region of the burnt areas; which Figure 2 shows to be some of the most severely burnt areas. While this relationship is not quantified in these figures, they point to the existence of invasive species monitoring and burnt area assessment procedures that could be strategically integrated to form an important new capability. Our goal is to build on the significant investments that have been made in these existing programs to better quantify the relationship between fire and invasive species ecology than use this knowledge to create a powerful new tool for NPS land management decisions.

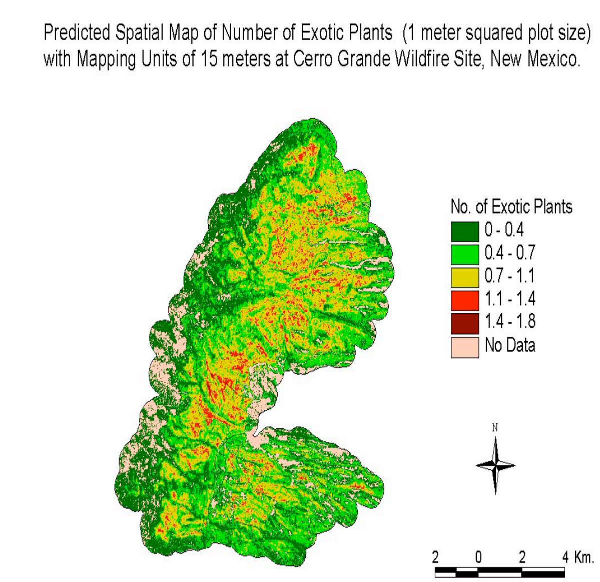
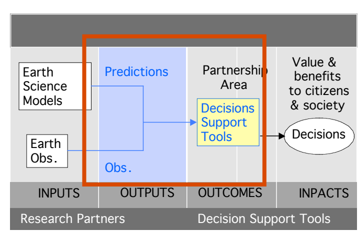


Figure 4

2.3. *Innovative plan to apply Earth Science results to NPS park management plans*



Our project brings together two distinct capabilities developed by two different government agencies to create a wholly new approach to integrated resource management decision making. We will take a series of inter-related steps to merge existing Earth science results in a way that can guide NPS decisions on invasive species control and fire ecology.

A. Model one or more invasive species habitats throughout each park region.
B. Create maps of likely invasive species habitats throughout the region (through the ISFS).

C. Establish a record of burnt areas since 2000, overlay this record with the invasive species habitat maps, and explore the relationship between invasion and fire disturbance
D. Use up-to-date burnt area locations and invasive species habitat maps to inform park managers of critical areas that may need treatment against invasion
E. Use invasive species habitat maps to identify areas within prescribed burn units that are likely to be invaded.
F. Extrapolate in space and time post-burn ecological assessment conducted at limited field locations by modeling the relationship between the ecological assessment point values and remote sensing and GIS layers (through the ISFS).

Knowing the location of both the established invasive species as well as potential habitat is extremely important in the efficient use of limited resources for monitoring each park system's invasive species. Step A will initiate the proposed effort to utilize the current information and existing inventories described above. These data will be ingested into the ISFS. Then the validated linear or logistic regression techniques available through ISFS (Figure 3) will build on the existing studies and park expertise to relate the field data to multiple remote sensing and GIS layers to model suitable habitat for invasive species. The initial species of interest include bird vetch in Alaska; cheatgrass, bull thistle and wooly mullein in the Sequoia & Kings area; and Canada thistle and Dalmatian toadflax in Yellowstone and leafy spurge in the GYA. For the GYA, we will coordinate with the predictive modeling ongoing at MSU.

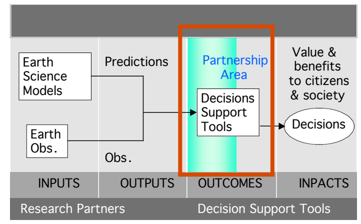
Using the modeling and relationships established in Step A, Step B will use the ISFS to produce maps of likely habitat of the species of interest (similar to Figure 4). Steps A and B can be iterated as new field data are collected and improved remote sensing and GIS layers become available. This is a key advantage of the high temporal resolution of MODIS products and the parallel computing environment for landscape scale mapping available through the ISFS.

Step C will use both the NPS maps of burnt areas (available through the National Burn Severity Mapping Project) and MODIS active fire and burnt area products. All burnt areas (prescribed and wildfire) will be ranked by overlaying each burnt area on an invasive species habitat suitability map. This will show burnt area "hot zones" that were suitable habitats for invasive plants and had experienced fire disturbance between 2000 and 2005. For each "hot spot" area we will note if any control or treatment was applied and the presence and relative dominance of an invasive species. This tabulation will help establish if controls were effective or if the absence of control led to invasion. We will also use monitoring plots, such as the 34 vegetation/fire monitoring plots in Yellowstone, to establish and test the relationship between fire occurrence and plant invasion.

In step D, any MODIS active fire and burnt areas within a given park system reported from 2006 on will be overlaid with the invasive species habitat suitability map to create current "hot zones" in near-real-time. Park personnel can manage these areas based on the insight from Step C.

Steps E and F will help incorporate the invasive species habitat maps into the park's fire management program to locate areas for prescribed burns and monitor the ecological recovery of burnt areas. All other criteria being equal, an area that is less suitable or further from invasive species habitat would be a better site to burn than a site that is more suitable, or adjacent to, habitat suitable for an invasive plant species. Therefore we can rank potential prescribe burn sites based on invasive species habitats near that site. Prescribed burns should occur on those sites least likely to promote invasion (Step E). For all prescribed burn sites, the field data collected by the NPS will be ingested into the ISFS where remote sensing and GIS layers will help model and extrapolate the ecological parameters measured in the field. The NPS "fire effects sampling sites" will provide field data on both ecological recovery parameters and monitoring for invasive species in burnt areas. These data will be ingested into the ISFS to model recovery parameters and invasive species using the MODIS vegetation index time series, vegetation index from other satellites (e.g., TM, ETM+, and ASTER) and the GIS layers available in the ISFS (Step F).

2.4. Management plan and partnership arrangements



The management plan will grow from the following key components:

- Individual quarterly status conference calls between NASA/ISFS and each park region.
- Annual meeting of entire team (likely to be as one- or two-day "add on" to the ISFS meeting) to inform all team members of the national needs, present the work at each park, and decide on steps for the next year.
- Attendance at the annual NASA application meeting (as described in the solicitation).
- Utilizing the customer survey and time-line management components integral to the ISFS's management structure (more in the section on performance measures).

The partnership between NASA Goddard Space Flight Center (GSFC) and NPS will involve several personnel from NPS working at the national level, a NASA lead scientist from ISFS and members of the MODIS science team. Morisette, NASA GSFC, will be responsible for integrating the NPS field data into the ISFS, developing the models within ISFS to map invasive species habitat and fire recovery parameters, and providing the park with resulting maps. NPS national-level personnel include Benson at the National Interagency Fire Center and Welch, Invasive Species Monitoring Coordinator with NPS, employed through Colorado State University. Benson and Welch have the responsibility to ensure that the proposed effort will meet the national level decision support needs of NPS. To help manage the initial work of integrating the ISFS output into the NPS decision support, we will request funding for a support person at the national level via a Master's level graduate student, co-located with the NPS invasive species lead at CSU. In addition, NASA GSFC will request 0.5 FTE of contract personnel to support the additional workload brought to the ISFS under this proposed work. Further, three individuals from each of three park systems will participate in the proposed work: (1) an invasive species contact, (2) a fire ecology contact, and (3) a geospatial/GIS information manager. Benson, Welch, and Morisette will work with the leads on their specific domain to ensure this effort supports park-level management decisions. Dr. Roy, University of Maryland, will contribute his scientific and technical expertise concerning the preparation, supply, and interpretation of MODIS fire products for NPS. Additional details on personnel time and travel plans are provide in the cost plan. In summary, the personnel matrix for the proposed work includes:

	Fire Ecology	**Invasive Species**	**Geospatial systems**
NPS national level	N. Benson	B. Welch	Mike Story
	(+ Master's level graduate student at CSU)		
NASA personnel	J. Morisette	J. Schnase	ISFS Eng. Team
	(+ UMd – D.Roy MODIS fire product leader)		
	(+ contractor support personnel, from 0.5 to 1.0 FTE)		
Alaska	J. Allen	J. Heys	B. Sorbel
Sequoia & Kings	T. Caprio	A.Demetry	P. Lineback
Yellowstone/Tetons	E. Miller	C. McClure	A. Rodman

2.5. Plan to transition results to operational agency and/or extent results broadly

The ISFS is deployed as a Web-based system that presents options for applying a series of models to available datasets yielding predictive model results and maps. Over the next several years, the joint USGS/NASA effort will transition the ISFS to an operational system within the USGS-led National Institute for Invasive Species Science (NIISS). This operational system will be established to accept users from government agencies, universities, industry, and the general public. During the three years of the effort proposed here, models of invasive species habitat will be developed for one or more invasive species for each park system. This activity will help jump start the NPS's use of ISFS. The invasive species field data collected by NPS personal will be made available as datasets within the ISFS. As such, The proposed work will provide a strong user base that can help test and guide the operational implementation of the ISFS (see letter of support from Thomas Stohlgren, NIISS Director, and John Schnase, NASA's ISFS director). Since the larger area around the parks involves USDA Forest Service (USFS) land, we will make any data resulting form this project known and available to the USFS. Also USFS personnel will be invited to join in any meetings or telecons of interests. We hope this additional coordination will assist the USFS to also utilize the operational results from our project (see letter of support from Tom Bobbe)

In addition to facilitating the use of the ISFS by the NPS, the proposed effort will help better integrate the MODIS active fire and burn scar products into the ISFS and provide valuable feedback to the developers of these products. This will be facilitated by Roy, the lead science developer of the burnt area product (Roy et al., 2002, 2005a) and Morisette, the validation coordinator for the MODIS science team (Morisette et al., 2002). Further support is supplied in the letter from Dr. Justice, the MODIS land team discipline leader.

Focus on the individual fire and invasive species management experience at each of the three park systems in our study will be balanced with the need to consider how other National Parks can use the resulting decision support tools. The variation among the three focus park systems will help us consider a range of issues. The NPS national leads on fire ecology (Benson) and invasive species (Welch) will help ensure that the tools built by the proposed effort can be applied to other parks to support their invasive species and fire management plans.

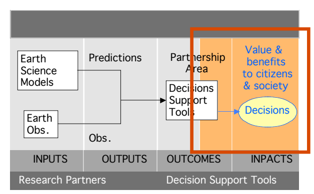
2.6. Issues affecting project success and the approach to address them

The project success will be subject to the accurate and timely remote sensing products. Both the MODIS fire and vegetation index product have been validated (http://landval.gsfc.nasa.gov/MODIS/), and it is safe to assume these products can deliver the anticipated results needed for the proposed work. Work is underway to quantify the accuracy of the MODIS burnt area product in southern Africa (Roy et al. 2005b) and more recently in other fire regimes around the world (Roy et al. 2005a). Establishing its accuracy in North America will be an important study for the MODIS science team. The interaction between the MODIS science team and the NPS staff will help quantify the accuracy of the burnt area product (letter of support from Justice). Having Dr. Roy serving as a member of our team will provide direct insight on the product and its application to our proposed work. Since May 2003, the ETM+ sensor has experienced a failure in its "scan line corrector" (http://landsat.usgs.gov/pdf/2003junelmu.pdf). This issue can cause gaps in the imagery in the east and west 1/3 of the ETM+ scenes. This implies the need for burn severity monitoring since May 2003 to consider alternative images. This should not cause a significant problem since NBR data can be extracted from TM as well as ASTER data.

We assume the ISFS will successfully transition to an operational system. We believe this is a safe assumption given the high priority of ISFS for both the USGS and NASA invasive species programs. Plans are in place to transition an operational system to USGS/NIISS by FY08. More questionable may be the ability of the ISFS to accurately map the likely habitat for a given invasive species. The accuracy of such a map will depend on the region and species. However, the elevation, soils, and vegetation data available within the ISFS, coupled with the existing surveys conducted at parks, can no doubt be combined to create informative maps. It is important to note that we are not proposing to map the location of *individual invasive species*, but rather *habitat suitable* for a given species. We will consider known locations of an invasive species and the characteristics of those locations. We then map those areas containing similar characteristics throughout the park. The ISFS is used to quantify which characteristics are important and model the relative weight of those characteristics in predicting suitable habitat. Mapping individual species is a far greater challenge. We believe mapping likely habitats is feasible and sufficient for our proposed work.

The results will need to be adopted by park personnel. Our approach is to directly involve park personnel representing fire ecology, invasive species, and geospatial systems throughout this process. Given the urgency and importance of monitoring and controlling invasive species emphasized by NPS personnel and their ongoing guidance in the development of the products, we expect the results to be directly relevant and applicable to their management needs. The geographic overlays, polygons of "hot zones," and a straightforward ranking system proposed will provide park personnel with an intuitive and easy-to-use system, further ensuring that the results will be implemented and influence park decisions.

2.7. Expected results



This project will bring together Earth science resources for the first time to simultaneously address the interrelated challenges of fire and invasive species ecology with the national park system.

The anticipated benefits include:

- Improved protection of ecosystems in national parks via enhanced exclusion of and more control over invasive species.
- Improved prevention and early detection of invasive plant species for the NPS and associated partners—high priorities for NPS.
- User support and feedback on the new MODIS burnt area product.

The improved decisions that will result are:

- National Park manager decisions on how best to manage burnt areas with respect to invasive species—considering both prescribed fire, wild land fire use, and wildfire suppression.
- Prescribed burn plans that explicitly include fundamental information on when and where to set prescribed burns to reduce risk of invasion.

We believe the improvements are entirely feasible given the existing Earth Science results and the availability of the ISFS. We also believe these improvements are critical given the pressing demands on the National Parks to address fire ecology issues and protect against plant invasion.

3. Performance measures

This project will use the ISFS "client survey," which has been established within ISFS, to better understand the client's work, objectives, needs, and progress using the ISFS. Here the client is the three national parks as well the NPS national programs. An outcome from this survey will provide a baseline measure of the client's current system, establish their requirements, and track their use of the ISFS. This existing component of the ISFS will directly support the benchmarking of the proposed work with tailored modifications to address the specific fire cycle – invasive species work proposed here. The client surveys will be executed annually to measure perceived improvements over the course of the project, with modifications made to the ISFS in response to this feedback.

We will look to the individuals at the parks to answer the following questions:

1) Are you able to ingest the maps into the park's geospatial information system (geospatial contact, asked upon delivery)?
2) Does the invasive species habitat map look reasonable (invasive species contact, asked upon delivery)?
3) Does the MODIS burnt area map look reasonable (fire ecologist, asked upon delivery)?
4) Did the invasive species habitat map influence invasive species monitoring and control decisions (invasive species contact, asked within 9 months of delivery)? If so, what is the value of this additional decision making information?
5) Did the invasive species habitat map influence fire management decisions on when and where to conduct prescribed burns and/or monitoring at burn sites (fire ecologist, asked within 9 months of delivery)? If so, what is the value of this additional decision making information?
6) Did any plant invasion occur in management areas where actions (to burn or not to burn at a given time or place) were based on the use of these tools? If so, what is the most likely component that contributed to this failure? (park invasive species control leads asked annually)

Steps 4 and 5 require a method to quantify the value of the increased information. There are likely to be too many confounding factors to simply compare the area of plant invasion before, during, and after our study. Primarily, modifications to the landscape may not be "linear" through the time period of this study (2000-2008). For example, the rates for human population, development, and transportation increases in Alaska for 2005-2008 may not follow the rates observed between 2000 and 2005. With this, we plan to quantify the performance of our effort by focusing on only burnt areas and estimating the proportion of burnt areas that become infested with an invasive species. This will help normalize the data across years, while respecting our focus on the interaction between burnt area and plant invasion. Mathematically, this performance measure is expressed as:

$$\textit{invasion to burn ratio}_y = \frac{\text{total acreage of burnt area that became invaded}_y}{\text{total acreage of burnt area}_y}$$

The historical data from field surveys and remote sensing will be use to estimate this ratio for 2000 to 2005. Data are not available for complete coverage across all parks, also burned area may not be available due to persistent cloud cover. Statistical sampling of the existing data will be used to produce unbaised ratio estimates for each park. Because of the delay in the invasive plant becoming established, the numerator in the equation cannot be estimated until the following year. Indeed, for a given burnt area, once invaded, the amount of area occupied by an invasive species is likely to increase beyond the first year after the burn event. To quantify the effects of our efforts within the time frame of this study, we will only consider the amount of a given burnt area occupied by an invasive at the first anniversary of the fire event. We will refine the invasion to burn ratio by separating the proportion of invasive species areas in both prescribed and wildland burns. For both prescribed and wildland fires, success will be measured by a reduction in the invasion to burn ratio.

We will track the amount of time and cost dedicated to removing or controlling invasive plants within burnt areas. Again, we will distinguish between prescribed and wildland fires. By better directing the location of prescribed burns, we hope cost of controlling or removing invasive species within prescribed burns will be reduced. However, the added awareness and directed response for mitigating invasive species in wildfire area may actually increase the time and effort directed to controlling against plant invasion (with this initial cost being offset by stopping the invasion before it becomes established). For these reasons, success will be measured by the reduction in time and cost dedicated to controlling invasive species on prescribed burns. The time and cost dedicated to controlling invasive species on wildland fires will be documented but not use as a measure of success given the three year time-frame for the proposed work.

We will also track the technical components of our use of the ISFS. All analysis methods and predictive output will be maintained in the ISFS database. An initial (baseline) state will be defined and created, by recording:

- the initial field and remotely sensed data used to generate the initial habitat predictions
- statistical modeling analysis routines and programs
- modeled output—regression equations and uncertainty maps

Throughout this study, additional field data and/or new remote sensing product will be integrated into ISFS and new predictive models will be run. The baseline output can be then compared with this subsequent output to measure:

- greater prediction accuracy
- less error in the residuals

Validation and verification of ISFS output will be based on statistical “cross validation” (setting aside a portion of the data to check the model) and boot-strapping (repeated cross-validation iterations) as well as utilizing statistical/geostatistical theory to assess the accuracy of the model.

4. Schedule

The following table lists the major phases of the project and their duration.

Major milestones are highlighted in bold.

Task	Date	Dependency Notes	Accountable
Preliminary activities			
Execute ISFS "client" interview/survey	Fall '05	ISFS Client Survey	Morisette/ *Schnase*
ISFS Benchmark Report Published	*Fall '05*		*Schnase*
Recruit MS student at CSU	Fall '05		Welch
Recruit contractor at GSFC for ISFS support	Fall '05		Morisette
Draft NPS-specific ISFS requirements	Winter '05	Client survey results	Morisette/ ISFS Eng. Team
Initial Benchmark/Evaluation Report	Winter '05		B-M-W*
Integration of Earth Science results into ISFS			
Integrate fire, burnt area, veg. Index MODIS products into ISFS	Ongoing, start winter '05	ISFS ingest tools	Morisette Roy
Integrate study sites' invasive species field data and GIS layers into ISFS	Ongoing, start winter '05	Data accessible	Welch
Ingest historical NBR data ('00-'05) into ISFS to produce overlay	Winter '05		Welch
Identify and stage Landsat scenes for 3 study sites to produce NBR	Start with '05 fire season	Nat.Burn Severity program	Benson
Combining Earth Science data and ISFS modeling			
Develop models for one or more invasive species for each park and deliver resulting map to geospatial specialist at each park	Spring '06	Required data ingested in ISFS	Morisette/ Welch
Iterate with parks on the quality and use of the invasive species habitat maps	Ongoing, start spring '06		Morisette/ Welch
Establish "hot zones" from 2000-2005	Spring '06		B-M-W
Explore relations between historical burnt and invaded areas	Ongoing, start summer '06		Welch/ M.S. student
Calculate "Invasion to Burn" ratio for 2000-2005	Fall '06		B-M-W M.S. student

** "B-M-W" = Benson, Morisette, and Welch*

Schedule continued…

Task	Date	Dependency Notes	Accountable
Ongoing actives and transition to operational			
Use invasive species maps to Identify prescribed burn sites	Ongoing, start spring '06		B-M-W
Produce and ingest into ISFS field data from prescribed burn sites.	Ongoing, start spring '06		Morisette
Collect and ingest updated ecological data on prescribed burn sites	post-fire on prescribed fire sites		Benson
Collect and ingest updated invasive species surveys on all burn sites	post-fire on prescribed & wildland fire sites		Welch
Calculate "Invasion to Burn" ratio for 2006-2008	**Ongoing, start spring '07**	**ecological data updated**	
Refine NPS-specific ISFS requirements	**Winter '05**	**'06 & '07 Client survey results**	**Morisette/ISFS Eng. Team**
Team management activities			
Quarterly Team Telecon & Kickoff	Oct '05	All team members present	Morisette
Quarterly Team Telecon to each of the three parks	Winter '06 – Summer '08		Morisette
Annual Science Team Meeting #1	May '06		B-M-W
NASA Application Meeting #1 (report result from year 1)	2006		B-M-W
Annual Science Team Meeting #2	May '07		B-M-W
NASA Application Meeting #2 (report result from year 2)	2007		B-M-W
Annual Science Team Meeting #3	May '08		B-M-W
NASA Application Meeting #3 (report result from year 3)	2008		B-M-W
Use invasive species - fire activity relationship to adjust park fire ecology plans	2007-2008	results from ISFS and 1st year of this project	Benson
Use invasive species - fire activity relationship to adjust park invasive species management plans	2007-2008	results from ISFS and 1st year of this project	Welch
Publish paper on invasive species - fire activity relationship	by 2007		B-M-W MS student
Publish paper on use of MODIS products for invasive species monitoring	by 2008		Morisette Roy
Present results at meeting and conference which team members may otherwise attend	opportunistically		all

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